Tracking of Returnable Packaging and Transport Units with Active RFID in the Grocery Supply Chain

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Abstract

The fresh products supply chain still has room to improve and increase efficiency and even become an intelligent supply chain by means of automating simple but valuable data flows which will be the foundations and first stage for developing new value-added services. The Spanish company ECOMOVISTAND has developed an innovative and ecological packaging and transport unit, called MT, for the grocery supply chain, which can be used in the entire product cycle; that is, the MT serves (1) as packaging at the producer, (2) as transport unit, (3) as storage at warehouses, and (4) as display stand at the supermarket, all in the same mechanical system, being thus a Returnable Packaging and Transport Unit. An MT needs the support of information technologies to achieve its true potential. In this paper we show the work developed in collaboration with ECOMOVISTAND in order to turn the MT into an intelligent product platform by embedding Active RFID tags. Data flows are integrated into an information system, called MEGASTAND, which allows to track MTs over the entire supply chain and provide value-added services to the customers.

Key words: Active Tags, RFID, Middleware, Web Services, Supply Chain, Identification, Tracking, Traceability, Cold Chain Control
PACS:

1. Introduction

A quick look at the supply chain of consumer goods reveals that traditional procedures are still most common in the landscape. Even though these procedures have become highly optimized, it seems that a technological ceiling has been reached. In other words, cutting down the costs of a particular process of the logistics and global supply chain, i.e. from the producer or manufacturer to the end consumer, requires nowadays a huge effort [1]. Nevertheless, the sector keeps seeking a greater degree of automation that might go beyond the actual concepts, procedures, and assumptions. Partly, this search for innovation is a consequence of larger retailer mandates on suppliers [2] but also of increasingly stricter regulatory compliance [3,4]. And both retailers and regulatory bodies have strong reasons for their requirements. Just a closer look on how the supply chain operates may back up some of these reasons, as we will see.

A typical supply chain is a complex amalgam of actors which need coordination, collaboration, and information exchanges among them to increase productivity and efficiency [6,7]. Every day millions of transport units (cases, boxes, pallets, and containers) are managed worldwide with a limited or even with a lack of control and knowledge of their status on real time (visibility on the supply chain) by the actors. As an example, CHEP [8], the world's largest pallet and container leasing company, has more than 285 million units, of which more than 200 millions are wooden pallets. They have to face logistics and economical problems to provide on time service with a bounded quantity of pallets due to the inaccuracy on where a pallet is and for how long it has been there. Thus, it is not surprising that major retailers push to finish this lack of control by forcing suppliers to adopt appropriate technologies (the Wal-Mart mandate [2], for instance).

Let us now look at our target sector, the grocery supply chain: fresh fruit and vegetables. All over the logistics supply chain millions of pallets are disposed every year only in Europe. Even though millions of these wooden pallets might be reused, it is still necessary to mass-produce new ones every year. The several levels of fresh products packaging (primary, secondary, and tertiary) generate a variety of residues depending on the stage of the product cycle. In fact, this sector is responsible for the generation of thousands of tons of all kind of residues just in Europe every year. The European Union, aware of this problem, has passed demanding packaging directives to be complied

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with [3]. The environmental policy goals are: to decrease or even to prevent the use of packaging, to recover and recycle all residues, and to make the producer responsible for the waste, as well as for the costs of recovering and recycling. These rules are crucial for a sustainable growth, but pose an extra cost for the actors of the supply chain. In addition, there is another important European directive since January 2005, the traceability of consumer goods [4]: it forces to register any steps, used materials, manufacturing processes, etc., during the entire life-cycle of a product. If a batch in bad state is found, it must be recalled from the market as quickly as possible. Therefore, there must be an efficient procedure to trace the affected batch with absolute guarantees [5]. The traced information must be registered for a few years, which gives a hint of the vast amount of information to be collected, processed, stored, and managed. Finally, controlling the temperature of perishable products along the supply chain (cold chain control) is an important issue because of both sanitary and economical reasons [9]. As concluded in [10], cold chain management requires very careful temperature control and quick reactions, that is, accurate and timely information on where and when the cold chain has been broken. With the previous examples, we have just brought a few of the issues within the context of grocery supply chain, which support the need for an intelligent supply chain that provides automated collaboration and information exchanges among their actors [11].

Cold chain control and traceability demand an increase in the in-transit visibility of a pallet and its carried products. Therefore, automated collection of information flows in real time or, at least, in a bounded time is becoming increasingly important for the grocery supply chain. However, current data capturing technologies are based on attached barcode labels. Barcode technology is a robust and cheap solution with well-known and tested systems. Nevertheless, scanning a multitude of labels is a slow, one-by-one and error-prone process [12]. Hence, Passive RFID has drawn a lot of attention as a revolutionary data capturing technology to be used both on pallets or on cases. However, Passive RFID deployment at the supply chain has not taken off as clearly as foreseen. From our point of view, in accordance with reference [13], pp. 18, two reasons may explain this situation:

- *Cutting down costs.* Because of the high number of transport units, the sector concentrates on cutting down their cost. A wooden pallet is already a cost-effective solution. It seems that users still do not clearly perceive benefits in relation to the additional cost of adding a passive tag to each pallet.
- *RFID perceived utility.* RFID is sometimes perceived as a mere substitute of barcode labels within the already established procedures and services, rather than as a potential generator of new value-added services, which avoids failures and saves money.

Regarding utility, the obvious solution is to offer better and new services. Indeed, RFID can generate new data flows but it is useless by itself if there are no better and new value-added services based on data management [14]. Regarding costs, the previous literature [12,15] has identified an additional key component needed to obtain a quick amortisation of the investment: the use of returnable transport units. Clearly, returnable transport units and adequate tracking technology complement each other when addressing the aforementioned issues: while returnable transport units may help to comply with waste regulation, apart from other operational and ecological benefits, there is still a need for procedures that ensure efficient and loss-free management of containers [15]. On the other hand, an *appropriate* RFID technology not only supports cold chain control and traceability, but also provides asset visibility, which, in turn, may improve management of containers [14].

The Spanish company ECOMOVISTAND [16], aware of the issues discussed above, has developed an innovative and ecological packaging and transport unit, called MT, for the grocery supply chain. The MT goes one step ahead of conventional reusable containers by providing additional interesting features (see Sect. 2), and it may be used as a standalone solution. However, the company is highly interested in offering tracking, tracing and cold chain control as value-added services. The Telematics Research Group from the Polytechnic University of Cartagena is collaborating with ECOMOVISTAND on developing the foundations of an innovative logistics system by means of Active RFID and the application of Information Technologies. In this paper we show the architecture and design aspects of MEGASTAND, the RFID and middleware support for the MT. It covers both RFID device development and control and management middleware based on Web Services.

From a methodological point of view, this paper contributes to design science research [17]: a problem of relevance (residue reduction, traceability and cold chain control) is presented; an artifact that addresses the problem is shown (the MT with embedded tracking and monitoring functionality, and the integration software); the design solution is based on both business and technical requirements, and the system components and alternatives are discussed with rigour (as derived from the effective use of the knowledge base [17]); and, finally, instances of the artifact are described (our implementations). However, as we have recently started a pilot trial, a thorough experimental evaluation of our design is left as future work. All the design has been refined in an iterative process, in close collaboration with the company.

The rest of the paper is organized as follows. MT features and the company business model are presented and discussed in Section 2. Technological requirements to control and manage a population of MTs over the supply chain are discussed in Section 3. The MEGASTAND System Architecture is described in Section 4, focusing on the developed Active RFID system and the Web Services solution. Related work is reviewed in Section 5. Finally, Section 6 provides conclusions and future work.

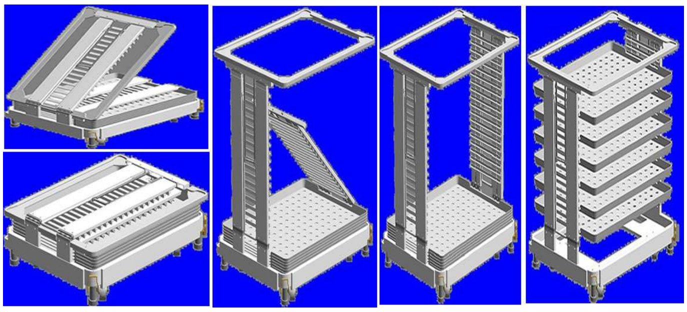

Fig. 1. MT Returnable Packaging and Transport Unit (several positions)

2. MT: A returnable ecological system for packaging, transport, storage, and display of products

A simplified overview of the grocery supply shows the following operations: (1) From Producer to Distribution Warehouses products are packaged (primary and secondary), put on pallets and delivered on trucks. (2) From Distribution Warehouses to Retailer/Supermarkets, received batches are inventoried, stored and shipped when a retailer order is received. (3) From Retailer to Consumers, batches are inventoried again and placed on display stands (usually long shelves). Intensive manual labor is required all over these steps for plastic film wrapping and removing, case inventoring and storing, arranging of display shelves as well as for recycling/collecting empty cases, pallets and all type of waste packaging produced.

To improve the efficiency of this supply chain operations, ECOMOVISTAND has developed and patented a novel mechanical system called MT, which is a special type of Returnable Packaging and Transport Unit intended to integrate several functions of the logistics supply chain of groceries (Fig. 1, 2, 3 and 4). MT is mainly made of last generation plastics, developed with the technical support of the General Electric Plastics Division in Spain[1], with high mechanical endurance and an expected operational lifespan of more than 10 years. An MT goes a step ahead of a pallet or a container, due to its properties and functions:

(i) Enhanced mobility. It can be easily handled either by people, because of its attached wheels, or by forklifts. The latter carrying several MTs at a time, as shown in Fig. 3(b).

(ii) Optimized dimensions. MTs fit in a truck (Fig. 3(a)), optimizing space. They can be folded and stacked, saving room in warehouses (Fig. 2(a)).

(iii) Package for products. MTs have seven removable trays to directly put the products (without cases or boxes) at the producer facilities (Fig. 2(b)), cutting down costs and waste (Fig. 4(b)).

(iv) Improved product transportation and shipment. MTs decrease manual handling to a minimum, avoiding damage to fresh products.

(v) Display stand. A loaded MT is directly used as display stand at supermarkets (Fig. 4(a)), speeding up the placement and replacement of groceries.

(vi) Recovering and cleaning. At the end of the cycle MTs are recovered, cleaned and used again in another cycle. Therefore, it can be considered as a Returnable *Packaging* and Transport Unit.

In brief, the MT features provide benefits in all the distribution cycle (even at retailers) in ecological, operational and economical terms.

(a) Folded and stacked MTs

(b) Automatic loading of bananas on MT, from Eurobanan Canary Islands

Fig. 2. MT usage at the producer

(a) MTs inside a truck

(b) Forklift lifting MTs

Fig. 3. Handling of MTs at warehouses

(a) MTs as display stands at supermarket

(b) No need of additional packaging like boxes or plastics for fruit

Fig. 4. Exposition and selling of goods in a supermarket

[1] This plant has recently been sold to the Saudi company Sabic, www.sabic.com

2.1. *Business Model of ECOMOVISTAND*

The MT is a novel and challenging system for the grocery supply chain and even though it may be profitable as a standalone solution, the company has committed to providing novel value-added services with *low investments* and minimum business processes adaptation on the customer side. Therefore, ECOMOVISTAND has decided to adopt a business model with two major components:

(i) *MT pooling service.* MTs are leased to customers. Hence, it is crucial to control and track any MT, partly due to its value compared to a conventional pallet, but also because the population of MTs should be kept at a minimum in order not to exceed the system cost deployment for rental services.

(ii) *New and value-added services to its customers.* Services play a key role if ECOMOVISTAND is to increase its clients interest in adopting the new system. In fact, the clients can benefit from RFID services with minimum investments, since most of the needed infrastructure and supporting technology is provided by ECOMOVISTAND. At the moment, planned services for the customers are: supply chain visibility, cold chain control and product traceability. The final goal is to extend these services in the future, providing real-time inventory or supermarket stock control.

3. Technological needs and requirements

Active RFID [7] is the core of the solution proposed to achieve the aforementioned business needs. MTs are tracked by attaching an RFID tag to them. Thus, RFID Readers are needed in check-points along the supply chain. In addition, a RFID data integration and control middleware is necessary. Let us first review RFID constraints posed by the ECOMOVISTAND business model:

– Long range readings. MTs are carried by forklifts and move through large, open warehouses and dock gates. Besides, this capability is key to future service extensions, such as smart shelves.
– Monitoring of perishable goods. Temperature tracking capability is a crucial value-added service. Hence, RFID tags must incorporate a temperature sensor.
– Full read/write capabilities. Tags carry the identifiers of the items on the trays in the MT, which must be updated every time the load changes.
– Ensuring Reader seamless integration into the customers facilities with minimum impact to their information systems.

In short, RFID tags should incorporate at least data memory, a temperature sensor, long range and nearly 100% success reading capability. Regarding the first requirement, an RFID tag should have enough data memory available to, for example, electronically store the barcode labels (such as EAN13 or EAN128 [18]) of the products associated to the MT content. Clearly, Passive RFID technology does not meet the requirements at the moment. In fact, Passive technology range is too short, dependent on tag location and orientation, and surrounding materials.

Since the MT is a high valuable asset, the costs of a more expensive active tag with the desired capabilities can be justified. Moreover, Passive RFID Reader portals at choke points or entry doors are rather expensive (more than 3000 euros for just the Reader and required antennas at the moment) and hence their deployment along the entire supply chain is, if not unfeasible, rather questionable, specially if clients have to deal with Readers cost. Our vision, on the contrary, is to have cost-effective RFID Readers which can be installed along the entire supply chain with minimal deployment costs.

Finally, the pooling service needs a Logistics Center which gathers and manages the RFID data flows. Together with the RFID devices, we have developed an information support infrastructure called MEGASTAND, a middleware for managing, controlling and exposing RFID data. For this tool, the only assumption on the available technology at the customer site is to have access to the Internet, so that the RFID Readers on customers facilities connect to the Logistics Center. In the following sections we describe the architecture and main components of both RFID framework and MEGASTAND middleware. However, let us remark at this point that our system could be implemented not only with MTs but also with other closed-loop asset management system. Moreover, a different RFID technology could be integrated with reduced effort.

4. MEGASTAND System architecture

In this section we describe the architecture of the information framework designed for the MT. The design process has been led by the company business model. As said in Sect. 2.1 ECOMOVISTAND deals with leasing the MT and providing the infrastructure needed to automate product traceability and tracking as value-added services. However, the company neither integrates its products into the customer information framework nor manages the customer systems. This business model poses two fundamental requirements on the architecture:

(i) It should not impose any given technology on the customer side. All the customer data is under their own control and management, by their own information system. ECOMOVISTAND just provides the means to access information about MT location and monitored data.

(ii) Similarly, it should not rely on any specific hardware or system arrangement in the customer sites or warehouses along the circuit.

Realizing that RFID technologies and trends are changing quickly at the moment, an extra requirement is mandatory: the architecture should allow seamless integration of future technologies and standards.

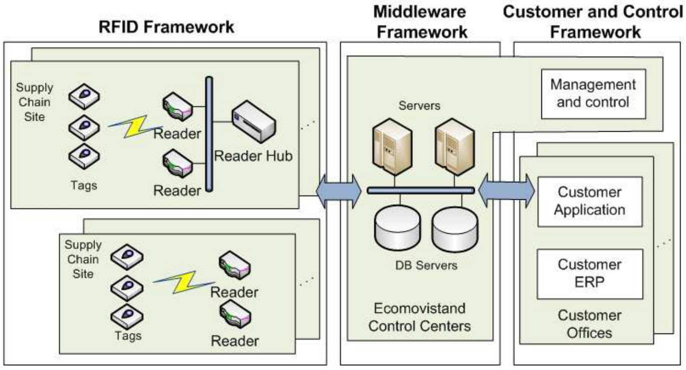

Fig. 5. MEGASTAND frameworks and their physical mapping. RFID Framework components are located in supply chain sites; Middleware Framework components are located in ECOMOVISTAND Control center; C & C Framework has two types of applications: those customer-related running on equipment in customer offices, and those control-related which are in Ecomovistand Control Center. Blue arrows represent typically Wide Area Network communications between components.

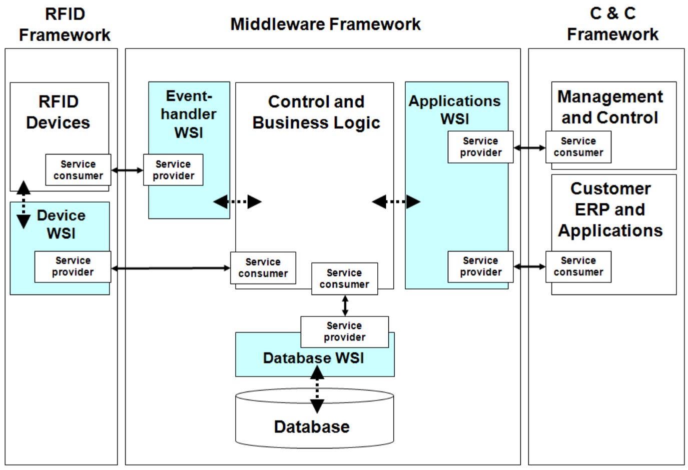

Fig. 6. MEGASTAND Web Services Interfaces. Solid arrows indicate Web Services provision/consumption. Notice that RFID Devices provide control functionality via Device WSI, whereas consume middleware functionality via Event-handler WSI. Dotted arrows indicate no WSI interaction.

To accomplish these goals we leverage existing Service-Oriented Architecture (SOA), the common approach, but we extend it to a recent new concept called Service-Oriented Device Architecture (SODA) [19]. The SODA approach integrates a wide range of physical devices into distributed IT enterprise systems, by establishing a set of well-defined interfaces (Web Services Interface, WSI), independent of the programming language and computing platforms on which they run. In our case, programmers deal with the RFID framework in the same way as they use business services in the classical SOA approach. Therefore, SOA provides the abstract interoperability layers that allow integration of ECOMOVISTAND data into different customer systems, whereas the SODA extension supports the integration of different RFID devices into the information systems. Let us first describe our architecture globally and justify our design decisions. In next sections, we will go through the implementation details of the different blocks.

MEGASTAND architecture consists of three different frameworks:

(i) RFID Framework. It includes Active RFID devices and their software.
(ii) Middleware Framework. It comprises database and application servers, and middleware software on the ECOMOVISTAND side.
(iii) Control and Customer (C & C) Framework. Hardware and client applications on the customer side as well as ECOMOVISTAND control and management applications.

Figure 5 illustrates these frameworks and their mapping onto physical devices and sites. All the components of the three frameworks are distributed between supply chain sites (supplier and logistics warehouses, picking platforms, etc.), ECOMOVISTAND Logistics Center and customer offices.

The inter-framework interactions are performed through Web Service Interfaces (WSI), as depicted in Figure 6. All of them expose a WS-*-compliant [2] web services binding interface for accessing the different functionality via SOAP/HTTP [20]. The rationale behind each WSI is the following:

– *Applications WSI.* This interface exposes the services offered to both control and customer applications. This is the main entry point to the MEGASTAND functionality, used to decouple it from its final representation, and the gate to the middleware binding framework between applications and RFID devices. There are two classes of service consumers for this WSI: on the one hand, ECOMOVISTAND control and management applications The exposed functionality allows to monitor the status of RFID Readers and configure them, whereas the management functionality deals with customer information, MT stocks and breakages and other business operations. On the other hand, customers may use this interface to retrieve information related to product location and routes, and monitored temperature. Different functionality is hidden or shown to the customer according to its access level. Customers can use this WSI in two ways: directly integrating functionality into its own ERP (Enterprise Resource Planning) or using the applications provided by ECOMOVISTAND.
– *Database WSI.* Data Base (DB) persistence services. This WSI acts as a hub for DB functionality. Future extensibility as well as scalability and performance are the desired features that motivate this interface. First, it adds an additional abstraction layer for the underlying DB implementation, which lets a way open to future extensions or upgrades. Regarding scalability and performance, it may seem that WS overhead does not precisely contribute to increase it, which is right *at the moment.* As depicted in Fig. 6, RFID data is processed and persisted through

[2] WS-* is the common way of referring to the suite of Web Services specifications, like WS-Security, WS-Messaging, etc.

control and business logic. However, we anticipate a future need for direct access to DB persistence by the RFID framework, probably via raw data filters [3]. For instance, we expect to install data cache (local database) in the larger customer sites. Therefore, we want to keep the flexibility of WS for this access, providing a standardized interface to DB. In this case, control and business logic would be relieved from the burden of processing these data. To sum up, the goal of this WSI is to provide flexibility for application extension, updating, and load balance.

- *Event-handler WSI.* RFID-generated events are passed to the middleware framework through this interface. It provides methods of communicating both raw RFID data and filtered events. Therefore, RFID Readers, and Reader hubs must implement Web Services client applications, which are able to use SOAP/HTTP. Although this approach implies increased complexity of Reader implementation posing an additional processing burden, which can be scarce for certain embedded Readers, we have adopted it due to the following reasons:
  - To minimize the problem of customer firewalls and proprietary technology. Readers are located in the customer sites, out of control of ECOMOVISTAND. We do not rely on any other customer technology else than HTTP infrastructure, which is a reasonable assumption.
  - To support different RFID technologies. At the moment, we have developed our own tags and Readers but other devices, such as EPC-compliant hardware [21], may be used in the future and we expect they support WS interaction.
  - To provide RFID devices with the service discovery capabilities of SOA. We expect to use Reader and Reader hubs with different capabilities and sophistication. Once installed, these devices register and update their capabilities through this WSI.
- *Device WSI.* Together with the Event-handler WSI, this interface extends the architecture from SOA to SODA. The purpose of this interface is twofold: first, it decouples RFID hardware from its clients and exposes control functionality to manage the RFID framework. Control applications send configuration commands. For instance, a group of RFID Readers can be instructed to periodically send status reports. Second, it provides application access to filtered and consolidated data, in a very similar way as that specified by ALE [22], by subscribing to events of interest. Device WSI clients post data requests and receive asynchronous responses through the Event-Handler WSI. Again, this approach requires the implementation of WS servers on the Readers side, but we consider it worthy for the reasons previously discussed. Implementation details can be found in Sect. 4.1.

[3] In Fig. 6 it would be another solid arrow between Database WSI and RFID Devices.

This architecture differs from other proposals like WinRFID [23] and BizTalk [24]. Both of them include a Reader adapter layer in the middleware, that is, RFID hardware is handled in the same way as other device drivers are. In our opinion, such an approach lacks flexibility and forces either the device providers to develop a number of drivers for different platforms or the middleware maintainers to implement adapters to different protocols. This is another reason why we decided to define WSI to the RFID framework, though trading off some performance.

We are combining two interaction models: synchronous and asynchronous. Most of the Customer and Control Framework operations are synchronous: management applications retrieve and update information such as orders, reports, shipment status, MT current and past locations, and so on. On the contrary, most of the RFID Framework activities are asynchronous. Control applications post commands to RFID Readers to adopt an operation mode and let them afterwards report RFID data asynchronously.

This architecture enables two classes of functionality: read-type and write-type functions. The functional requirements of the business model are achieved with read-type functionality: package-level tracking [15] and cold chain monitoring by collecting RFID data; product traceability by storing and managing all that information properly. Moreover, this functionality is offered with a high level of decoupling between the components: customers can either access relevant data directly via specific WS-client applications, or integrate it with its own ERP in a standardized way.

Write-type functionality supports other interesting applications. Let us first remark that efficient product traceability depends on the data model used [25,26]. MEGASTAND supports the use of an item-centric approach [25], since tracking is done on a package-level basis (the MT) and its current location is just another property of the information associated to a product. In fact, the use of Read/Write RFID tags provides the flexibility needed to implement this approach, since product code and other product-related information is carried by the item and can be modified/updated through the chain. Our architecture facilitates such functionality by providing a *two-way interface* between customers and products, using the SODA approach, which enables appending information *relevant for the supply chain operation*. For example, at a given site in the chain customers may add information about what to do with a product at the next appropriate site. Such information is sent by the customer through the Application WSI, then, the appropriate Reader is instructed (by a command posted via Device WSI) to store the information in the MT when it is identified. Eventually, another Reader retrieves and use it at the specified site. Of course, the amount of information is limited by the available RFID tag memory. Hence, tags should only carry information *relevant* to the supply chain operation. Indeed, tags should carry a link to product information stored in the backend systems of the producers. In this way, this architecture is compatible with distributed product databases, like EPC Information Services (EPCIS) [21], based on globally unique product identifiers [27]. Customers can access the identifiers carried by MTs through MEGASTAND and then query the appropriate backend systems. In any case, since tags carry information on the contents of the MT, it is also possible to use locally the data, without connectivity to centralized information sites.

4.1. *RFID framework*

RFID Framework is comprised of Active RFID tags, RFID Readers, and Reader hubs. In this section, we will describe their implementation details and the operation of this framework. RFID tags provide raw data in the form of identification numbers, customized data (such as barcodes of loaded items), and temperature readings. Readers collect raw data as input, then filter and process it, and communicate meaningful high-level events as output. Reader hubs add an additional data aggregation layer, which is necessary as the system grows in order to perform Complex Event Processing (CEP) [28] at the edge of the network so as not to saturate the middleware framework.

Active RFID Tags. As discussed in Sect. 3, Active tags are the most appropriate solution for ECOMOVISTAND. Commercial Active RFID systems are rather expensive and lack the flexibility needed to customize MT and develop future services. Therefore, we have designed and developed our own active tag with commercial off-the-shelf components. We have selected the Texas Instrument CC2510F32 System-on-Chip (SoC) [29] as the Active tag platform, operating at 2.4 GHz.

Currently, the functionality implemented on this platform is programmable temperature logging and generic data memory reading/writing. In addition, since battery depletion is a major concern for Active tags, we have developed and implemented an energy-conserving anti-collision procedure (whose details are out of the scope of this paper). Finally, these platform processing capabilities open the way for MTs to incorporate smart shelf functionality in the future.

Readers. Modularity has been the main design goal for Readers in order to achieve maximum flexibility and future extensibility. We plan to have a family of Readers with different capabilities. At the moment, Readers are composed of two components: an embedded computer (from now on, EC) and an independent RF interface. This design emulates that of WiFi access points: the independent RF module performs communication with MT tags, whereas the embedded computer implements functionality such as data filtering and aggregation and communication with middleware or Reader hubs.

The RF module will identify and interrogate tags, and it will send data to the embedded computer via a serial interface (either RS232 or USB). Hence, it operates as any other serial modem from the point of view of the embedded computer, driven by a number of AT-like commands. By keeping the communications interface between the RF module and the EC unchanged, we can seamlessly change any component in the future, and so achieve the modularity required.

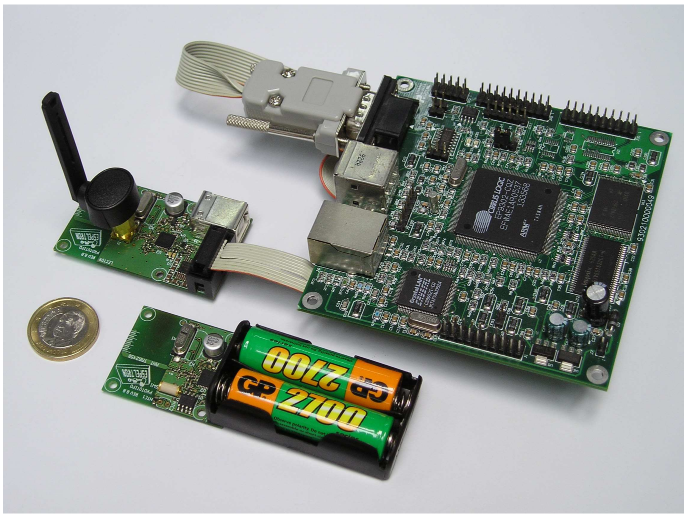

Fig. 7. Developed Active Tag and Reader

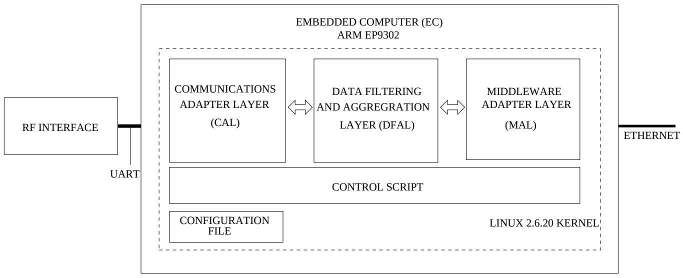

Fig. 8. Reader architecture and implementation

Inside the EC, functionality is also componentized as follows. We have defined a three-layer architecture for the EC software, illustrated in Fig. 8:

– *Communications Adapter Layer (CAL)*. This layer implements interactions with the RF interface, sending control AT-like commands (start and stop scanning, etc.) and receiving raw data (tag identifiers, temperature logging, and memory blocks).
– *Data Filtering and Aggregration Layer (DFAL)*. Raw data from CAL is filtered according to specified rules.
– *Middleware Adapter Layer (MAL)*. This layer handles middleware requests and notifications. As both a WS server (implementing the Device WSI) and a WS client. As client, filtered data is sent to the Event-handler WSI. As server, control and configuration commands are received and enforced as well as filtering rules, which are passed down.

An ARM9-based Single Board Computer is used as EC hardware, whose core is a 32 bit ARM EP9302 processor from Cirrus Logic. The OS is a Linux 2.6.20 kernel. On this platform we have implemented a version of each layer of the architecture. Every layer has been implemented as an independent process, communicating with each other via UNIX sockets. All the three processes are launched by a control init script and take configuration parameters from a text file. Again, we have taken this approach for the sake of modularity: layer functionality can be seamlessly updated by replacing the corresponding process as long as interfaces are kept fixed. CAL implementation just handles the serial ports and converts data formats. For DFAL, which we are currently working on, we have adopted the ALE specification data model [22] for reports, slightly modified to suit our data formats. Finally, we leverage csoap [30], an open source, lightweight SOAP library, for MAL WS implementation. This library has been used to implement both SOAP WS client and server. Communications with the Event-Handler WSI at this layer use an Ethernet interface.

Summarizing, we are developing a flexible and versatile platform for RFID Readers, whose capabilities have not been fully exploited yet. In fact, we plan to make the most of them in the future to obtain a family of Readers with different features.

Reader hubs. Reader hubs provide an additional aggregation and filtering layer. They are useful in large sites, where several Readers collect data from tags on different locations. Reader hubs smooth and consolidate data from Readers before passing them to the Middleware Framework, implementing a data cache (local database). We are currently working on the design and specification of these components, which we plan to implement on commodity PCs.

An important requirement of the RFID Framework has been auto/remote configuration and update capabilities at the Reader level. Let us exemplify these capabilities. After installing a new Reader at a customer site (a warehouse, for instance) and booting it, its first action is to execute the registry process: the MAL layer uses the Event-Handler WSI to inform the Middleware Framework about its recent availability. The business Logic confirms this registration and activates the Reader for the rest of applications. Immediately after, the Reader executes the update process: it communicates the version of its software components and configuration file, and asks for updates. In case updates are available, they are downloaded (it can be done also via WSI, since it supports the SOAP MIME attachments extension) and installed. Readers can perform this activity periodically or be instructed to carry it out remotely via the Device WSI.

4.2. *Middleware and C&C frameworks*

The Middleware Framework comprises database, integration software and servers. A five-layered logical architecture was considered suitable for the Middleware Framework, as depicted in Fig. 9.

RFID devices, as well as database servers, fall logically into the Data Source layer. Obviously, from the point of view of the upper layers, RFID devices are just another

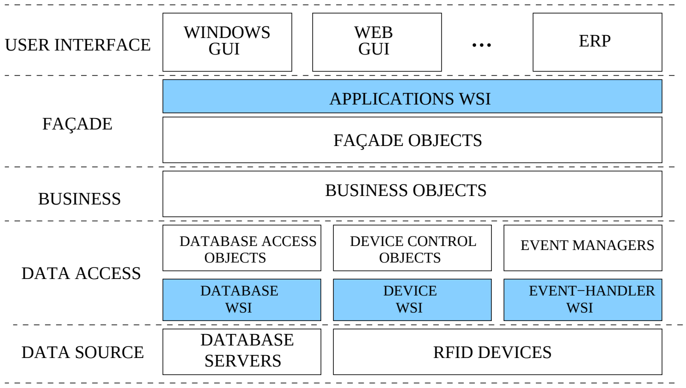

Fig. 9. Middleware Framework logical architecture

data source, (whose operation has been described in Sect. 4.1) interfaced via the Event-Handler WSI and the Device WSI, respectively. The MEGASTAND databases have been implemented on a Microsoft SQL Server 2005. They store all the information needed by the applications, which is retrieved via stored procedures to improve performance.

The Middleware Framework is implemented at the Façade, Business and Data Access layers (represented in Fig. 6 as the box labeled "Control and Business logic"). For their implementation, the Microsoft .NET platform has been used, being C# the programming language, on a Windows 2003 Server. The Façade layer is made of the classes and methods that provide to the upper-layer applications with access to functionality (exposed through the Applications WSI). They also check access control rules. The Business layer comprises all the software that models domain-specific data and that glues together the rest of the components. Business objects are either tracking-specific data types, representing entities like Item, Reader, Tag or Location, enterprise management-specific data types, representing entities like Invoice or Customer, or utility data types, like collections and validation rules. Finally, the objects that handle all the Data Source interactions (exposed through Database, Device and Event-handler WSIs) fall logically into the Data Access layer. Although a thorough discussion on the interaction of all these entities [4] is out of the scope of this paper, we provide a simple example: an Event Manager object receives a list of identified tags as well as a reader ID and a timestamp in XML format through the WSI. It converts them to the appropriate collection of business data types and performs validation checks. Afterwards, it instantiates a Database access object that persists the information to the underlying database. Finally, it informs the object in charge of notifying the occurrence of the event to interested applications.

Let us now discuss some issues of this architecture and our particular implementation.

Stateless model. By implementing all the middleware interfaces as Web Services we are implicitly using a *stateless* design. In fact, *most of* the service calls are served

[4] This interaction is commonly called "business logic"

by instances of objects created on the fly, which perform a number of operations and are immediately disposed. That is, middleware objects do not keep state between calls. All the persistent information needed is stored in and retrieved from the database. This is also the approach taken, for instance, by J2EE [31] enterprise applications, because of its better processing efficiency, which can be further enhanced by using object pooling and other server services. Therefore, an important part of these three layers is implemented as a set of Dynamic-Link Libraries (DLL), loaded upon request on the WS calls to the Web Server.

Asynchronous operations. However, the stateless model cannot provide all the required functionality. Since RFID data is received asynchronously, some mechanism able to react to RFID events and, more importantly, to communicate those events to applications is necessary. Therefore, following the classical publish/subscribe pattern, we have introduced the Event Managers, entities that match asynchronous service requests and RFID events. Event Managers are implemented as Windows Services (like UNIX daemons), thus residing permanently in memory. They register and handle application requests, and they ship notifications upon request completion. There exists a number of possible implementations of this callback process [32]. Event Managers offer two callback modes: WS-enabled applications supply a reply endpoint for notifications, according to the WS-Eventing specification, whereas for non-WS-enabled applications a proprietary callback process and data format has been developed. Although the latter non-standard mode should be avoided when possible, it has been included to facilitate application development.

Security. Security is a complex issue in the realm of Web Services, which has been covered in some of the WS-* specifications. However, our more restricted scope of application allows some simplifications. First, ECOMOVISTAND services are not publicly available, but restricted to its registered customers and, second, they do not spam multiple service providers, but are two-party conversations. Therefore, general data confidentiality, integrity and authentication are achieved by using HTTP over SSL (https). Authorization or access control, on the other hand, is enforced at the Façade layer on a role-based approach.

Finally, on top of the hierarchy is the User Interface layer. The applications developed for the C&C Framewok fall into this layer. ECOMOVISTAND control and management applications have also been programmed in C#. The company plans to provide a basic MT tracking web-based application or customized applications on agreement with the customer. Technical support is provided in case the customer agrees to integrate functionality into his own enterprise information system.

5. Related work and discussion

Our work for MT information technologies support has spanned two areas: Active RFID tag development and RFID middleware integration. In these areas, EPCglobal [21] is the industry-driven reference for RFID standardization. Together with the Electronic Product Code (EPC) numbering scheme, they are developing standards that describe all the components and architecture of a global network of RFID tags, Readers, and information systems, which would allow sharing information over an entire supply chain. Before discussing relationships with this suite of specifications, let us first consider our work from an overall perspective.

The need for returnable transport units as a solution to costs and waste regulation has been previously pointed out in the literature [15,14]. The authors also review, from a general point of view, the management of these containers and remark the benefits of single package level tracking as opposed to account based monitoring. They also highlight the need for a loss–free rotation of the units. Regarding the latter, the effect of adding asset visibility to the management of returnable transport units has been recently evaluated [14]. The evaluation shows that shrinkage can be effectively reduced (around 10%) and, more interestingly, total costs can also be reduced remarkably if proper management actions accompany visibility. Authors emphasize especially the need for the tracking system to have adequate data analysis and reporting capabilities.

As for tracking specifically, a thorough discussion can be found in [13], with an emphasis on issues related to the applicability of RFID technology. One of the conclusions is that RFID potential benefits are the highest when used with returnable transport units and read/write tags. In fact, this statement generalizes a previous conclusion drawn when the grocery supply was analysed [12]. This work provides three reasons for the lack of RFID applications in the sector at that moment: (1) need to build your own system due to a lack of system integrators, (2) disputes about sharing costs and benefits along the supply chain and (3) lack of standardisation. In this respect, our system may help overcome these adoption problems, since it addresses all of them to some extent: first, integration is what MEGASTAND basically provides; second, Ecomovistand assumes most of the infrastructure costs (except for the Readers at the customer sites); third, companies benefit from the services, irregardless of the technology employed.

The most similar approach to ours comes from iGPS [33]. This is a new pallet rental company launched by Bob Moore, a former CHEP [8] CEO. Whereas CHEP is attaching passive tags to wooden pallets as an extra service (PLUS ID), iGPs is launching an all plastic pallet pool with embedded passive tags. iGPS pallets share some features with ECOMOVISTAND MTs, that is, returnable, recyclable, ecological units. However, there are also clear differences: unlike MTs, which cover all the distribution cycle and can be used as display stand at the retailer sites, the iGPS pallets just provide the traditional carrying functionality of a wooden pallet. To make up for the cost of this pallet (2.5 times as much as a wooden one), iGPS also offers RFID tracking as an unavoidable value-added service. The main difference here is that iGPS uses Passive technology. To overcome the difficulties of passive reading, the pallets have to carry four identical tags. Each tag includes an Electronic Product Code (EPC) Global Reusable Asset Identifier (GRAI) [21]. In addition, pallets also include barcodes, as a redundant identification system. ECOMOVISTAND MTs on the contrary, can be identified with a single Active tag, which in addition benefits from programmability and sensor data acquisition. That is, a MT can be programmed to carry a desired identifier (either GRAI or other codes) and it can sense a number of physical magnitudes as additional value-added services. iGPS software infrastructure is provided by its partner Xterprise. Its solutions are built up on Microsoft BizTalk RFID Server [24]. Since iGPS uses standard passive tags, whose drivers are already developed by the corresponding RFID tag vendor, BizTalk may be a sound solution to quickly build the system. However, as discussed in Sect. 4, in our opinion BizTalk and WinRFID [23] approaches lack the flexibility we wanted and would have made us develop additional drivers for our tags to plug in the middleware framework, jeopardizing also future extensibility as well as our plan to provide a SODA approach for the RFID framework.

Going down to more particular aspects of our work, Active tag technology is somewhat confusing in the literature. The differences between a wireless sensor [34], a Bluetooth-enabled device [35] or an Active tag [36] are blurred. In many cases, it is just a matter of intended application of a given device. EPCglobal has specified physical interfaces for Passive tags (Class 0, I, II) and an anticollision protocol independent of the tag class called Gen 2. However, specifications for Active tags (Class III, IV, V) are not available yet. The ISO 18000-7 [37] is another recent standard which does specify the physical interface for Active tags at 433 MHz. Faced with the lack of a mature standard, we have developed our own tags on a platform flexible enough to incorporate future changes. The disparity of recent proposals for Active RFID tag implementation supports our approach. Among them, RollCall shows an interesting novel design for an inventory management system [38], focusing on identification performance. On the contrary, in this paper we focus on an architectural overview of the entire Active RFID framework, showing Reader implementation details that are relevant for its integration with the rest of the system.

Finally, several aspects of RFID middleware have been discussed in open literature. WinRFID [23] provides a RFID middleware architecture, as discussed previously. Wang and Liu [39] focus on a temporal-oriented data model for RFID data processing, querying and updating, and describe the Siemens RFID middleware architecture, which integrates this model. In reference [40], the constraints imposed by passive tags to RFID middleware are discussed. Basically, our approach and all these proposals share a common schema: a filtering layer at the edge of the network (Readers) together with a publish/subscribe-based event messaging system.

6. Conclusions and future work

In this paper we have shown the architecture and design decisions of the information technologies framework for the ECOMOVISTAND MT pooling service and value-added services.

The MT is an innovative Returnable Packaging and Transport Unit, which covers all stages in the grocery supply chain, from producer to retailer. The MT as standalone solution provides environmental benefits and costs savings, but needs additional technological support to reach its true potential. Active RFID may help the MT become an adequate platform on which to build the paradigm of Intelligent Products, since it allows an MT to store associated products content and exchange it without human participation.

With the aid of the MEGASTAND system, the MT addresses the need for traceability of grocery goods and cold chain control. Although some of the system features are based on ECOMOVISTAND specific business model, our architecture may be implemented with any other closed-loop asset management system. In this sense, this paper contributes to design science research by providing useful directions on how to address issues common to this information support systems.

Regarding contributions for RFID system design, we show how to address both traceability and cold chain control with an Active tag with sensory capabilities embedded in the transportation unit. Being reusable, it may take truly advantage of the tag read/write capabilities. Some additional advantages of Active technology are long range readings, which also avoids tag redundancy, and higher memory storage availability. Taking advantage of this we leave the contents carried by the tag open. Unlike other solutions, it allows to carry links to backend information systems as usual, but also richer data content and so the possibility of using it locally (off-line). The drawback of higher cost of tags can be balanced with the reduced cost of their Readers. In fact, a Reader with advanced functionality can be developed with cheap commercial off-the-shelf hardware, as we show, to obtain very low cost devices and achieve enough flexibility for future functionality. From our point of view, tag price draws too much attention, whereas Reader hardware deployment cost may have a more important impact on the feasibility of the project.

On the other hand, we contribute the description and analysis of a flexible and open middleware architecture. It is built upon SODA principles, leveraging Web Services as standard interfaces between different components in order to provide future extensibility and high decoupling. The

SODA two-way interface between customers and products is a unique feature compared to most of the existing solutions, and together with read/write tags allows automated in-transit updating of product information, which may lead to interesting applications. Moreover, though some of the functionality like cold chain control requires Active RFID, the MEGASTAND architecture is basically independent of the type of tags used.

Currently, we are deploying a pilot of the system with tracking (for ECOMOVISTAND and customers) and temperature logging functionality. We plan to show performance results and lessons learned in future papers. We are also working on the specification and implementation of reader hubs, focusing on adopting CEP approaches for their design. As a mid-term future work line, we are going to integrate our system into the EPC global network, by adopting EPC codes for the MT identifier and setting up EPCIS and ONS servers.

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References

[1] Bello, D. C., Lothia, R., Sangtani, V., "An institutional analysis of supply chain innovations in global marketing channels", *Industrial Marketing Management*, vol. 33(1), pp. 57–64, 2004.

[2] Roberti, M., "Wal-Mart Suppliers Discuss RFID", *RFID Journal*, Available at: http://www.rfidjournal.com/article/articleprint/956/-1/1/

[3] European Parliament. Directive 2004/12/EC of the European Parliament and of the Council of 11 February 2004 amending Directive 94/62/EC on packaging and packaging waste - Statement by the Council, the Commission and the European Parliament, *Official Journal of the European Communities*, L 47, 18.2.2004, pp. 26–32.

[4] European Parliament. Regulation (EC) No 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety, *Official Journal of the European Communities*, L 31, 1.2.2002, pp. 1–24.

[5] Bechini, A., Cimino, M., Marcelloni, F., Tomasi, A., "Patterns and technologies for enabling supply chain traceability through collaborative e-business", *Information and Software Technologi*, vol. 50(4), pp. 342–359, 2008.

[6] Choi, T. Y., Krause, D. R., "The supply base and its complexity: Implications for transactions costs, risks, responsiveness and innovation", *Journal of Operations Management*, vol. 24, pp. 637–652, 2006.

[7] Myerson, J. M., *RFID in the supply chain: a guide to selection and implementation*, Auerbach Publications, 2007.

[8] CHEP. Equipment Pooling Systems http://www.chep.com

[9] Likar, K., Jevsnik, M., "Cold chain maintaining in food trade", *Food Control*, vol. 17(2), pp. 108–113, 2006.

[10] Bogataj, M., Bogataj, L., Vodopivec, R., "Stability of perishable goods in cold logistics chains", *International Journal of Production Economics*, vol. 93–94, pp. 345–346, 2004.

[11] Pramatari, K., "Collaborative supply chain practices and evolving technological approaches", *Supply Chain Management: An International Journal*, vol. 1 2/3, pp. 210–220, 2007.

[12] Kärkkäinen, M., "Increasing efficiency in the supply chain for short shelf life goods using RFID tagging", *International Journal of Retail & Distribution Management* , vol. 31(10), pp. 529–536, 2003.

[13] Kärkkäinen, M., "Forwarder Independent Tracking Systems–Problem description and Solution Design Proposal", *Helsinki University of Technology*, 2003, Espoo.

[14] Johansson, O., Hellström, D. "The effect of asset visibility on managing returnable transport items", *International Journal of Physical Distribution & Logistics Management*, vol. 37(10), pp. 799–815, 2007.

[15] Kärkkäinen, M., Ala-Risku, T., Herold, M. "Managing the rotation of reusable transport packaging–a multiple case study", *Thirteenth International Working Seminar on Production Economics*, Igls/Innsbruck, 2004.

[16] Ecomovistand http://www.ecomovistand.com

[17] Hevner, A., March, S., Park, J., Ram S., "Design science in information systems", *MIS Quarterly*, vol. 28(1), 2004.

[18] GS1 GSMP Standards http://www.gs1.org

[19] Deugd, S., Carroll, R., Kelly, K., Millet, B., Ricker, J., "SODA: Service Oriented Device Architecture", *Pervasive Computing*, vol. 5(3), pp. 94–96, 2006.

[20] Newcomer, E., *Understanding Web Services*, Addison-Wesley, 2002.

[21] EPCglobal http://www.epcglobalinc.org

[22] The Application Level Events (ALE) Specification, version 1.0 *EPCglobal inc*, Available at: www.epcglobalinc.org.

[23] Prabhu, B. S., Su, X., Qiu, C., Ramamurthy, H., Chu, P., Gadh, R., "WinRFID–A Middleware for the Enablement of Radio Frequency Identification (RFID) based Applications", *Mobile, Wireless and Sensor Networks: Technology, Applications and Future Directions*, R. Shorey, C. M. Choon, O. W. Tsang, A. Ananda (eds.), John Wiley, pp. 313–336, 2006.

[24] Schwartz, K. D., "BizTalk RFID: Making RFID Deployments, Easy, Simple and Economical", *Microsoft White Papers*, June 2006. Available at: http://msdn2.microsoft.com/en-us/library/aa479354.aspx.

[25] Rönkkö, M., Kärkkäinen, M., Holmströn, J., "Benefits of an item–centric enterprise–data model in logistics services: A case study", *Computers in Industry*, vol. 58(8), pp. 814–822, 2007.

[26] Främling, K., Ala-Risku, T., Kärkkäinen, M., Holmströn, J., "Design paterns for Managing Product Life Cycle Information", *Communications of the ACM*, vol. 50(6), pp. 75–79, 2007.

[27] Främling, K., Harrison, M., Brusey, J., "Globally unique product identifiers–requirements and solutions to product lifecyle management", *IFAC Symposium on Information Control Problems in Manufacturing*, 2006.

[28] Luckham, D., *The power of events. An introduction to complex event processing in distributed enterprise systems*, Addison-Wesley, 2002.

[29] Texas Instruments www.ti.com.

[30] CSOAP, client/server SOAP library in pure C
http://csoap.sourceforge.net.

[31] Java Platform, Enterprise Edition
http://java.sun.com/javaee.

[32] Quian, K., Liu, J., Tao, L., "Asynchronous Callback in Web Services", *Proc. 7th Int. Conf. on Software Engieneering, Artifical Intelligence, Networking and Parallel/Distributed Computing*, pp. 375–380, 2006. O. W. Tsang, A. Ananda (eds.), John Wiley, pp. 313–336, 2006.

[33] iGPS. Intelligent Global Pooling Systems
http://www.igps.net

[34] Zhao, F. y Guibas, L., Wireless Sensor Networks. An information processing approach. *Morgan Kaufmann*, 2004.

[35] Siegemund, F., Florkemeier, C., "Interaction in Pervasive Computing Settings using Bluetooth-Enabled Active Tags and Passive RFID Technology together with Mobile Phones", *Proc. 1st Int. Conf. on Pervasive Computing and Communications*, pp. 307–387, 2003.

[36] Stanford, V., "Pervasive Computing Goes the Last Hundred Feet with RFID Systems", *IEEE Pervasive Computing* , vol 2(2), pp. 9–14, 2003.

[37] ISO/IEC 18000-7:2004 Information technology–Radio frequency identification for item management–Part 7: Parameters for active air interface at 433 MHz, 2004.

[38] Bhanage, G. D., Zhang, Y., Zhang, Y., Trappe, W., Howard, R. E., "RollCall: The Design for a Low–cost and Power Efficient Active RFID Asset Tracking System", *EUROCON 2007, The International Conference on Computer as a Tool*, pp. 2521–2528, 2007.

[39] Wang, F., Liu, P., "Temporal Management of RFID data", *Proc. 31st Int. Conf. on Very Large Data Bases*, pp. 1128–1139, 2005.

[40] Floerkemeier, C., Lampe, M., "RFID Middleware Desing: Addressing Application Requirements and RFID Constraints", *Proc. 2005 Conf. on Smart Objects and Ambiten Intelligence*, pp. 219–224, 2005.